Estimation of the Factors of Population Inflow in Inner City by using the Mobile Spatial Statistics : The Case of Obihiro City, Japan

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Abstract: Demographic changes due to aging population, dwindling birth rate, and population decline are particularly evident in rural Japan. Strategic shrinking and future aggregation are necessary to maintain effective urban functions. In this paper, we analyzed the influence of change the building use, rearrange or accumulate to the number of visitors in the inner city in order to support the measures for compact city with public transport system. Thus, multiple regression analysis was conducted by the follow two big data that are "Mobile Spatial Statistics" data that records the staying population in the urban space and "Urban planning basic survey" that records the building characteristics at the polygon level. As the result, the influence of total floor of each building type to the total number of population inflow in the case study city was revealed.

Keywords: Compact city, Mobile Spatial Statistics, Urban Planning Basic Survey, Multiple regression analysis

1. INTRODUCTION

Demographic changes due to aging population, dwindling birth rate, and population decline are particularly evident in rural Japan. In 2005, the average number of children born per couple was 1.26, however the number increased slightly to 1.39 in 2014 (Cabinet Office, 2014). The percentage of the total population over 65 years (known as the population aging rate) increased to 25.1% in 2014 (Cabinet Office, 2014). The issue of aging has significantly affected regional economies and social conditions, including medical and welfare services, employment, residence, and businesses. The effects of inadequate medical and welfare resources are particularly acute. Therefore, the need for future strategic shrinking and aggregation in response to demographic changes should be considered. Significant time will be required to plan and implement measures for the compaction of urban areas. Redevelopment and relocation of housing, along with renovation of transportation infrastructure, will be required to support economic development and social services in the face of declining birth rates and aging.

However, in order to actually plan the policy of compact city with public transportation network in local cities, it is necessary to consider selecting the type, scale and aggregation area of urban facilities, depending on the characteristics of the target city. Then, in this study, we analyzed the influence of change the building use, rearrange or accumulate of urban facilities to resident population in order to support the future compact city measures. For this purpose, we used the following two different big data that are "Mobile Spatial Statistics" data, which estimates small area population derived from the operational data on a mobile phone network, and "Urban Planning Basic Survey" data, which records the detail of building characteristics at the polygon level in a city.

This paper is organized as follows; Chapter 2 presents the scope of previous research, Chapter 3 outlines the Obihiro Metropolitan area that is used as the case study. And, we discuss resident population analysis based on the Mobile Spatial Statistics, In Chapter 4, multiple regression analysis is performed using the Mobile Spatial Statistics data and the Urban Planning Basic Survey. Finally, the conclusion is given in Chapter 5.

2. RELATION OF THE PRESENT STUDY TO PREVOUS RESEARCH

This section outlines previous researches on population decline and urban residential patterns. On the basis of the results of the 2005 Japanese census, Kaneko et al. (2006) used the cohort component method to estimate future population for the period 2006–2078. In a study of demographics and urban residential patterns, Koike (2010) used regional mesh statistics to classify population changes in the Tokyo metropolitan area into natural and social variations and also analyzed related trends on the basis of distances from downtown Tokyo and train stations.

In a study of sprawl and reverse sprawl of the city, Taniguchi (2008) compared long-term and micro-scale differences in activity and depopulation between sprawling in Okayama and other urban areas. Uemura et al. (2009) summarized building space reduction and other measures to counter reverse sprawl in Germany and discussed methods of applying such measures in Japan. Hayashi et al. (2009) defined areas with greater financial and environmental burdens and social costs resulting from disorderly land use as social hazards, and identified areas vulnerable to natural disasters as natural hazards. They also evaluated land use patterns in specific areas and proposed improvements to Quality of Life on the basis of depopulation of high-risk areas and reconcentration in urban areas. In addition, they discussed how the difficulty of short-term and compulsory land use changes in Japan makes it more realistic to concentrate populations in urban areas with policies that allow gradual relocation.

In a study on the Obihiro city that is the target of the present study, Matsumura and Fukui (2010) investigated relocation to housing complexes a new town in the southeastern part of the city. Many people had moved into the complex since its initial development in 1967, which was a period of high growth in Japan. The authors observed how low rents in public housing within the complex had attracted elderly and young people alike, resulting in a generational mixture that promoted mutual assistance in the community. The report also highlighted measures for the relocation of senior citizens owning detached houses. Under that approach, area revitalization in housing complexes would be promoted by providing public housing and services for the elderly and offering them houses previously occupied by younger residents, which were vacated due to senior citizen relocation. Arimura et al. (2013) identified the generational structure of residents and building age distribution by zone in Obihiro and estimated future population distribution by zone for the period 2010–2035. They determined the spatial distribution of people living in houses in the area. However, in this study, the main purpose was to estimate to identify the place of population and building aging in the city, the effect of consolidation of urban facilities on urbanization patterns to the number of population inflow in an inner city was not considered by limitation of transportation related data.

Here, with the proliferation of mobile phone usage and the development of ICT, a new statistical data called the Mobile Spatial Statistics (hereinafter referred to as MSS), which derived from the operational data on a mobile phone network, was developed to observe hourly population inflow for marketing and city planning in urban areas. The MSS estimates small area population that was consisted by hourly as time unit and minimum 500 square meters as a space unit in a city.

In a study on the MSS, Makita et.al. (2013) was performed to calculate deviation rates of the MSS population and to compare with the population of the Grid Square Statistics by Statistics Bureau of Japan. The result showed the MSS would be plausible for use in densely populated areas.

Applications of the MSS for urban planning are being accumulated in Japan. Morio et al. (2015) applied the MSS to PT survey in Tokyo metropolitan area and compared the resident population of the MSS and the PT survey by correlation analysis and trend analysis for each population attribute. However, this study mainly focused on evaluation of the value as a substitute the MSS for the PT survey. About the possibility of utilization of the MSS for the town management, Seike et al.(2011,2015) verified the reliability of the MSS, and grasp distribution of visitors from each attribute of the urban area. However, it was not discussed the relevance of buildings in cities and population inflow in these studies.

The present study was characterized by integrating and analyzing different 2 type micro data such as the MSS data for estimating the number of visitors in an inner city and the urban planning basic survey which includes building information in the city. By multiple regression model, we tried to grasp factors of the number of visitors in an inner city as people crowding for supporting compact city measurements. The authors tried to analyze by same approach at Obihiro city as the case study city (Arimura et.al. (2016)), but the number of the MSS data was limited and the scale of mesh size was 1 km square unit. Therefore, in this study, we tried to apply more detailed 500 square meter unit data in the same case study city, and the multiple regression model was also performed.

3. OUTLINE OF CASE STUDY CITY

3.1 Case Study City

The urban area of Obihiro in Hokkaido was selected for the present study due to its status as a local central city, its location on a plain where the topography has little influence on urban structures, and a downtown with a grid pattern that facilitates an easy understanding of the study results. Obihiro is located on the Tokachi Plain in eastern Hokkaido. The area is known for its flourishing agriculture (with extensive large-scale dry-field farming), tertiary industries (such as tourism, commerce, and service), and a pattern of urban development reflecting the goal of a garden city with urban and rural areas in harmony. Obihiro's 2013 population of approximately 170,000 makes it the sixth largest city in Hokkaido and a major urban area in the Tokachi region. However, the city's population has decreased since peaking in 2000, with demographic aging playing a significant role. Figure 1 presents the existing land use in the Obihiro city in 2009.

Figure 2 presents the relation of existing building age (left) and the resident population by age (right) in 2009. The population of residents under 40 years of age has been decreasing. In addition, many buildings were built in the 1970s and 1980s are now 30 to 35 years old. The data also reflect a decrease in new building constructions during recent years.

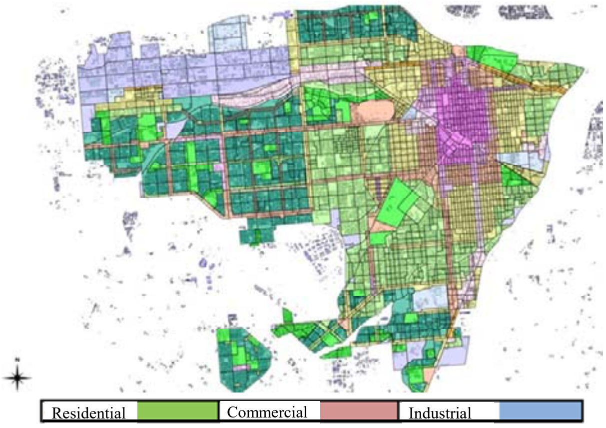

Figure 1 Existing land use in Obihiro (2009)

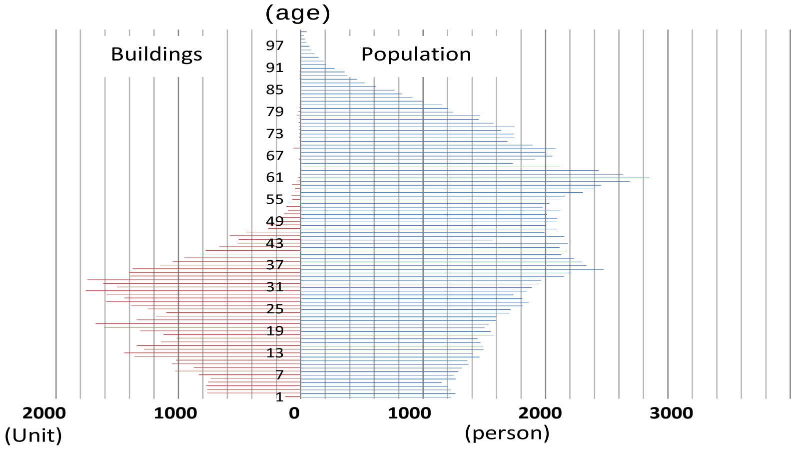

Figure 2 Distribution of buildings according to age of structure and residents (2009)

3.2 Data Overview

In the present study, the following two sources of data were used: the Basic Survey of City Planning in the Obihiro urban area and the MSS provided by NTT DoCoMo.

The Basic Survey of City Planning(hereinafter referred to as BSCP) is conducted approximately every five years, and its results provide data according to building type and year of construction with polygon information for each building. In the Obihiro urban area, 50,608 buildings were identified. They included 41,577 dedicated dwelling units, 4,652 apartment buildings, 1,907 general stores combined with housing, 473 food and beverage stores combined with housing, 269 workplaces with housing, and 1,730 offices combined with residential housing.

The MSS from NTT DoCoMo provided a new approach for characterizing the population distribution through statistical processing of the mobile network data, and estimates of the respective population meshes. These data differ from conventional techniques for estimating population in the following ways: 1) estimates reflect real-world population distribution according to the spatial distribution of the mobile phones and 2) the spatial extent of any subject area can be observed. In the present study, mobile spatial data for the 10/20/2013 holiday and the 10/23/2013 weekday were used to conduct a survey of person trips. Surveys were conducted at 2:00, 10:00, 14:00, and 19:00 within four time zones using a 500 meter grid of fluid population data.

3.3 Reliability verification of the MSS

The MSS statistical process the operational data of the mobile phone network, unlike exhaustive survey such as the national census. Therefore, it is considered that errors will be included in the estimated population.

Then, in this study, the correlation coefficient between the resident population by the national census in 2010 (hereinafter referred to as the national population) and the current population at 2:00 am as the population of night time estimated from the MSS (hereinafter, estimated population) was calculated. The results are shown in Figure 3 and Figure 4. Correlation coefficient showed high correlation as 0.72 for weekdays and 0.78 for holidays. As the result, it was possible to apply the MSS to the case study city that was even a low population density city.

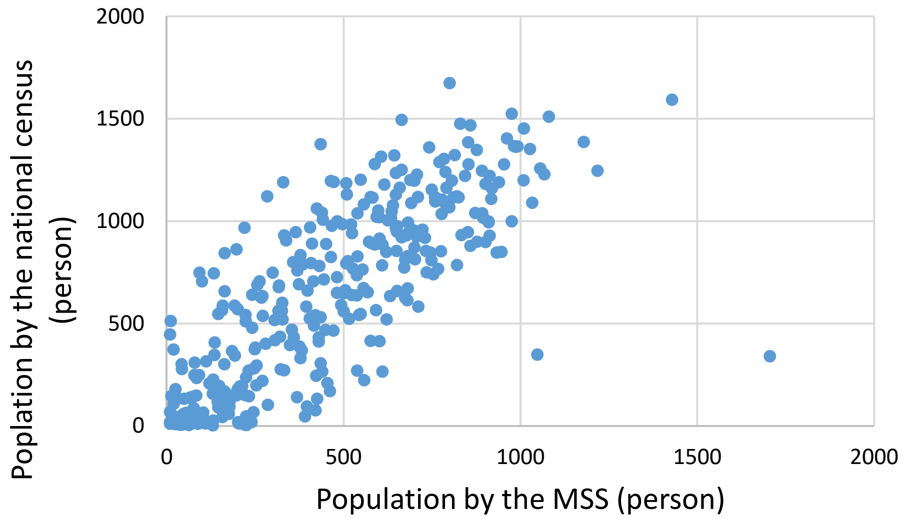

Figure 3 Scatter diagram of the national census and the MSS (Weekday)

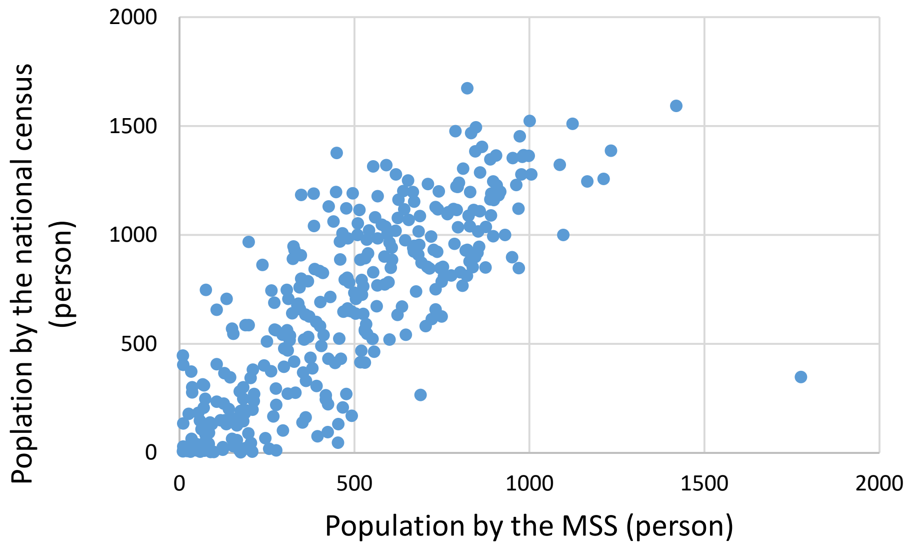

Figure 4 Scatter diagram of the national census and the MSS (Holiday)

3.4 Hourly population inflow in the case study city

The relation of spatial building distribution to population dynamics was estimated using the MSS. The observed hourly population of each mesh block in the MSS for existing population was calculated for 500 square mesh per hour. Here a population at 2:00 was assumed as the night-time population. The differences between the 10:00, 14:00, and 19:00 hourly mesh population and these night-time populations were calculated as an hourly mesh population for each mesh block and time zone. This hourly mesh population was defined as function 4, as shown below.

$$TP_{i,t} = P_{i,t0} - P_{i,t} \, , \tag{4}$$

where

$TP_{i,t}$	: Hourly population inflow in mesh i in time zone t (person/hour),
$P_{i,t}$	: Observed hourly population inflow in mesh i in time zone t (person/hour),
t	: Observed time zone (10:00, 14:00, 19:00),
t_0	: Basic time zone (2:00),
i	: Mesh number.

A multiple regression analysis was then conducted using the hourly population inflow for each mesh block and time zone as objective variables and building types in each mesh block as explanatory variables.

Here, Figure 5 presents the distribution of the hourly population inflow by time zone on weekdays and holidays. If the value of the hourly population inflow is positive, the population will increase compared to the nighttime population, which means that the population will decrease conversely if negative.

Regarding weekdays, an increase in the number of population inflow was shown in some areas such as the office area in front of the Obihiro Station and the industrial district area in the west Obihiro area. On the other hand, the population inflow decreased in areas with many houses such as the south-west side of Obihiro area. Thus, the distribution of the hourly population inflow at 10:00 and 14:00 was almost the same, but the people moving has decreased at 19:00 at the time of after returning home. Regarding holidays, the absolute value of the population inflow tends to be smaller than on weekdays. However, the meshes with increasing population inflow were widely distributed. Regarding the inflow to the commercial district, the increase and decrease of population inflow were small compared with the nighttime population at 10:00 in many meshes. At 14:00, the population inflow was concentrated in the area where commercial district and cultural education facilities, it seems that various activities such as shopping are active.

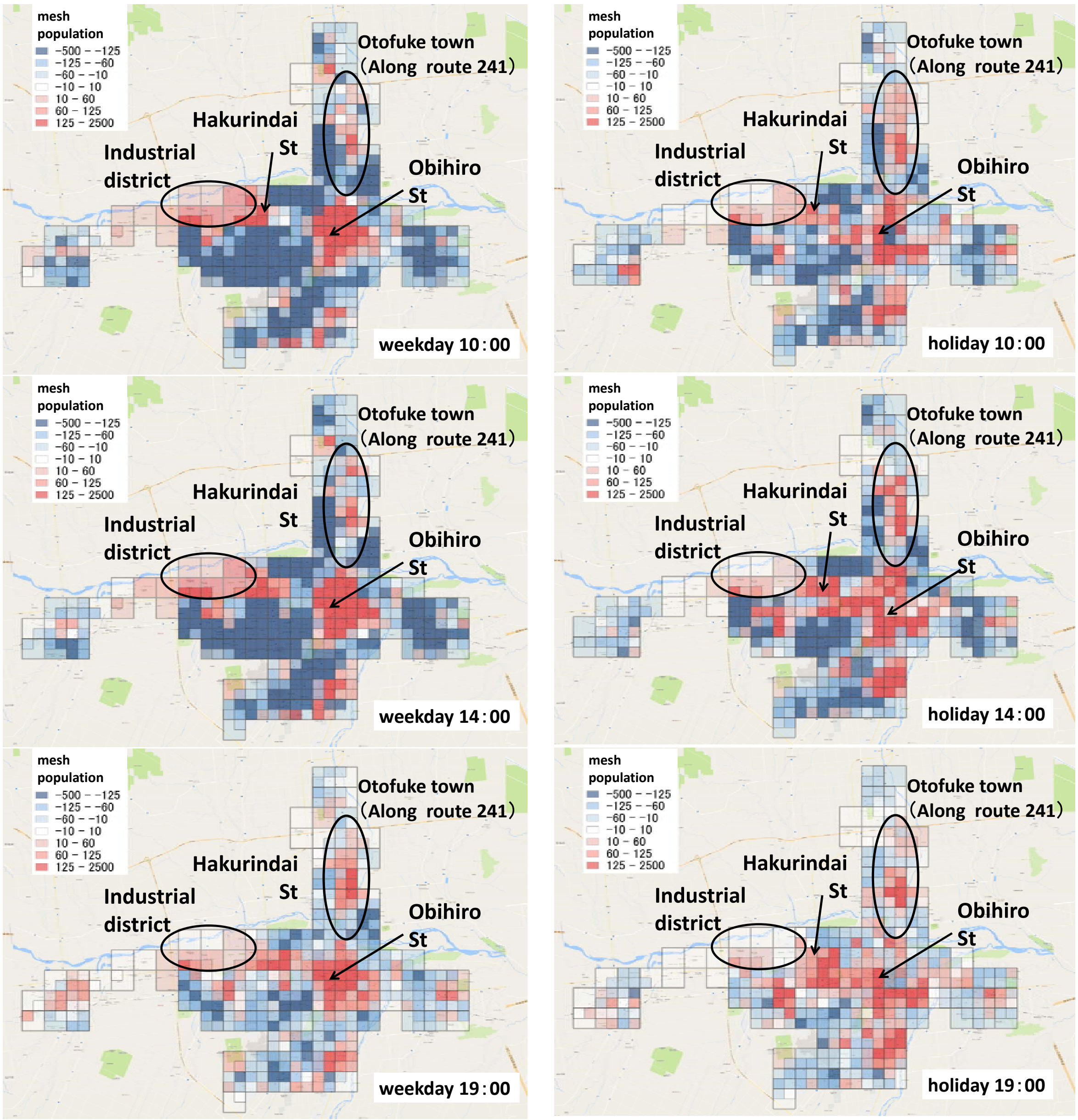

Figure 5 Distribution of the population inflow on weekdays(Left) and holidays(Right)

4. MULTIPLE REGRESSION ANALYSIS WITH MSS AND UPBS

As mentioned the chapter 3, the population of the population tends to affect the location of buildings with different uses such as commercial districts and residential districts. Therefore, in order to evaluate in detail and quantitatively the influence of such building use on the population inflow, a multiple regression analysis was conducted using the hourly population inflow for each mesh block as objective variables and the total floor area of each building type in each mesh block as explanatory variables. The stepwise method was used for variable selection in this study.

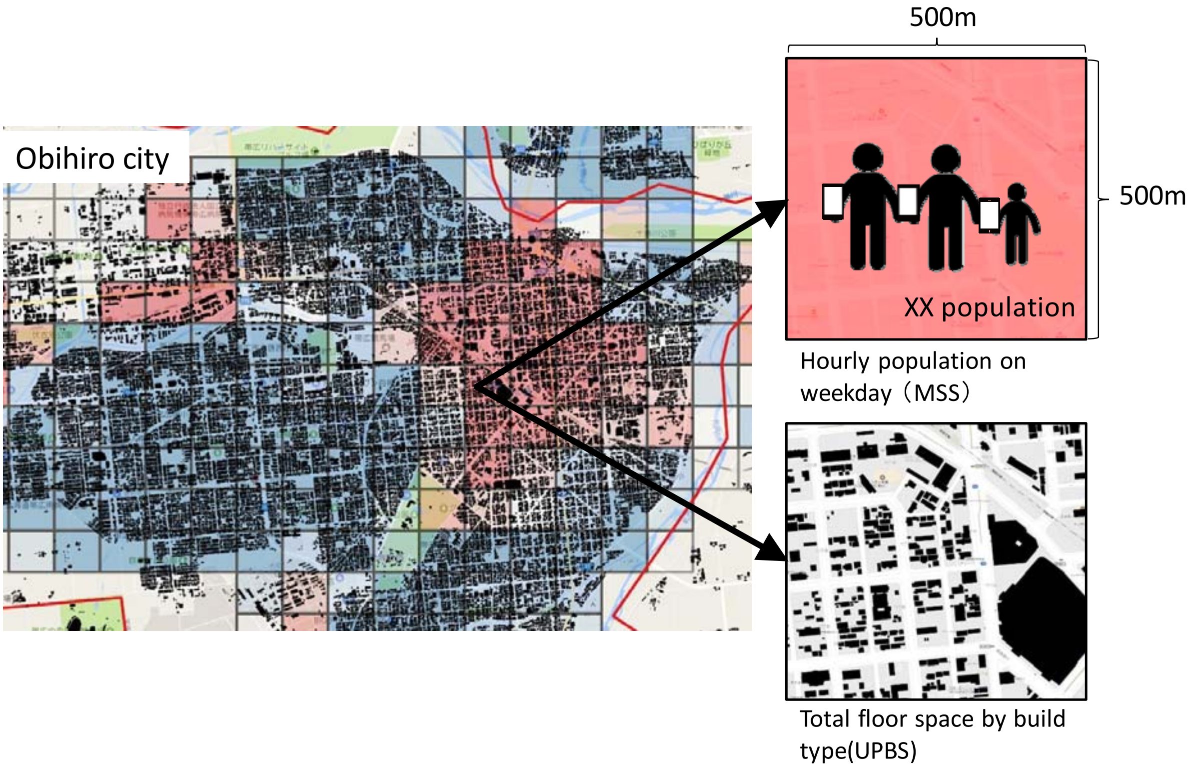

Figure 6　The objective variables by MSS and the explanatory variables by UPBS

A multiple regression analysis was conducted using the hourly population inflow for each mesh block and time zone as objective variables and building types in each mesh block as explanatory variables. Here, a multiple regression analysis was defined as function 5, as shown below.

$$y_{i,t} = \beta_{0,t} + \sum_{j=1}^{k} \beta_{j,t} x_{i,j} \tag{5}$$

where

- $y_{i,t}$: Hourly population inflow (person/hour) in mesh i in time zone t,
- $x_{i,j}$:Total floor area in each mesh i on each building type j as explanatory variables,
- $\beta_{j,t}$: Partial regression coefficient in mesh j in time zone t,
- $\beta_{0,t}$: Constant term in time zone t,
- i : Mesh number,
- j : Building type (31 types),
- t : Time zone (10:00, 14:00, 19:00).

Table 1 lists the results of the multiple regression analysis. The holiday analysis results were not used in this study because the coefficient of determination showed a low value. The coefficient of determination for the holidays became small, whereas the coefficient of determination for weekdays was relatively high. The reason was the population inflow for each mesh and time zone was estimated to consist with simple trip patterns that for weekdays. On holidays, however, the factors of population inflow could not explain only by building use because due to diversity of trip purpose on holiday and increasing the population inflow to the outside of Obihiro city.

Table 1　Results of the multiple regression analysis

Weekday 10:00

Explanatory variable name	Partial regression coefficient	Standard partial regression coefficient	t value	
Medical facility	0.008	0.101	2.787	**
Business facility	0.018	0.328	6.497	***
Welfare facility	0.269	0.130	3.613	***
Office combination house	0.019	0.172	4.402	***
Dedicated dwelling house	-0.005	-0.301	-8.201	***
Communication facility	0.043	0.199	5.035	***
Cultural facility	0.025	0.149	3.593	***
Game facility	0.029	0.170	4.022	***
Constant term	-51.070			
Adjusted R-square	0.619			

Weekday 14:00

Explanatory variable name	Partial regression coefficient	Standard partial regression coefficient	t value	
Business facility	0.018	0.341	6.545	***
Welfare facility	0.191	0.094	2.490	*
Office combination house	0.019	0.179	4.375	***
Dedicated dwelling house	-0.005	-0.287	-7.452	***
Communication facility	0.039	0.181	4.351	***
Cultural facility	0.029	0.171	3.909	***
Game facility	0.027	0.166	3.736	***
Constant term	-40.460			
Adjusted R-square	0.578			

Weekday 19:00

Explanatory variable name	Partial regression coefficient	Standard partial regression coefficient	t value	
General store combination house	-0.011	-0.295	-3.660	***
Office facilities	0.016	0.561	7.442	***
Office combination house	0.012	0.213	4.148	***
Shopping mall	0.004	0.118	2.145	*
Food and amusement businesses facility	0.120	0.199	3.603	***
Constant term	-31.509		−5.232	
Adjusted R-square	0.386			

The result shows at 10:00 on weekdays, medical, business, welfare, office combination house, dedicated dwelling house, communication facility, cultural facility, and game facility were selected as the explanatory variables. At 14:00 on weekdays, business, welfare, office combination house, dedicated dwelling house, communication, cultural, and game facility were selected as the explanatory variables. And at 19:00, General store combination house, Office facilities, Office combination house, Shopping mall, Food and amusement business facility were selected as features.

In the case study city, it could be inferred that there were not only fixed activities or movement patterns such as business commuting, but also a variety of activities on weekday. During working hours on weekdays, welfare, medical, and amusement facilities are selected and further exceed the partial regression coefficient of the business facilities. It is thought that Obihiro city's industry is mainly the agriculture and the characteristics of the aging society are being strongly expressed in the results. It is thought that the increase in elderly people with disposable time supports the increase of population inflow to medical, communication, cultural and amusement facilities on weekdays.

5. CONCLUSIONS

In this research, two big data that are the MSS and the UPBS data were integrated to analyze the influence of changing, rearrangement and accumulation of building types and space to population inflow in the Obihiro city as the case study.

The results obtained are shown below.

1) The reliability of this data is confirmed by comparing with the nighttime population inflow of the MSS data in the Obihiro city and the resident population by the national census.
2) We defined the difference between the staying population in 2:00(nighttime population) and the staying population at each time zone as the population inflow in each mesh, and visualized the spatial distribution. As a result, on weekdays, the population inflow to the commercial and industrial areas were increased, and at 19:00 it was found that increase of the population inflow around the Obihiro station and the commercial area in the Otofuke town. As for the holidays, the change in the population inflow is smaller than on weekdays, but it turned out that the entry into the commercial area appeared markedly at 14:00. By using the MSS data, it was confirmed that population inflow was easily observed even in a local city.
3) Multiple regression analysis was conducted by the MSS data and the UPBS data using the hourly population inflow as the target variable and the total floor area as explanatory variables. As a result, it was revealed that on weekdays medical institutions, welfare facilities, business facilities, etc. were extracted as significant variables.

In this study, we quantitatively evaluated the influence of the building use to the population inflow in the city, it was possible to evaluate the impact of the population inflow by the situation of the building type and total floor area. But estimation the future population inflow with population decline was not conducted. Also, in this study, since the analysis unit was limited to 500 square meter mesh, it is not possible to estimate more detailed population inflow in micro scale space where urban facilities concentrate in a narrow area. As challenges for the future, it is necessary to build the downscaling model for estimating the population inflow in finer space units that incorporates autocorrelation among meshes. In addition, high-resolution visualization should be conducted to assess potential impacts to city residents affected by the policies for the long-term increase in urban densities.

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